North Coast and Cascades Monitoring Network of the National Park Service

Use of Remote Sensing for Long-term Ecological Monitoring in the North Coast and Cascades Network: Summary of a Workshop

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Introduction

Long-term ecological monitoring of national parks became a servicewide priority in 1993, but progress was relatively slow until Congress appropriated funds for the Natural Resource Challenge in 2000. At that time, all natural area national parks were included in one of 32 networks nationwide and development of network-based monitoring began. Meanwhile, the USGS Olympic Field Station has been working with Olympic National Park since 1994, and with the North Coast and Cascades Network (NCCN) since 2000, to help develop their monitoring programs. The network includes Ebey's Landing National Historical Reserve, Fort Clatsop National Memorial, Fort Vancouver National Historic Site, San Juan Island National Historical Park, and Mount Rainier, North Cascades and Olympic National Parks.

We have long recognized that remotely sensed data, on scales spanning the range of aerial photographs to satellite imagery, might effectively address some monitoring needs of national parks, especially the large mountainous parks in the NCCN. These needs include:

- The need to monitor the large areas that are inaccessible by foot travel.
- The need to view some processes from the landscape perspective (e.g., disturbance size and pattern, especially disease, fire, and wind-throw; riparian and river channel dynamics; land-use patterns outside of parks; patterns of physiognomic vegetation distribution).
- The need to identify unique events throughout the parks (e.g., blow-down inside parks due to clearcut logging up to the park boundary).

We also realize that climate and vegetation of the Pacific Northwest pose significant limitations and challenges for remote sensing:

- Frequent cloud cover.
- Dense, multi-layered forest canopies comprised largely of evergreen trees.
- Expense of data acquisition and analysis.

To explore whether remote sensing might be feasibly used to answer certain monitoring questions identified by NCCN parks, the USGS Olympic Field Station and Olympic National Park organized a workshop having the following objectives:

1. Learn what information remote sensing techniques are capable of detecting, how much they cost, and what expertise, equipment and software are needed to analyze the data.
2. Learn which other agencies are using remote sensing, what data they are already collecting in national parks, and how we might collaborate with or access data from these agencies.
3. Develop a monitoring plan for use of remote sensing by parks in the NCCN that addresses previously identified monitoring questions.

Workshop invitees included representatives from NCCN parks, representatives from other land management agencies conducting remote sensing projects at or near the parks, and experts on various remote sensing techniques (see Appendix A for list). The meeting was held October 2-

4, 2002 in Port Angeles, WA. The meeting included a field trip to present background information, and presentations by technical experts and park service neighbor agencies. Next, workgroups identified strategies for answering specific monitoring questions. Finally, we summarized a plan for the effective use of remote sensing for monitoring in the NCCN (see Appendix B for agenda). In this summary of the workshop, we try to present the highlights and conclusions.

Brief Descriptions of NCCN Parks

The NCCN includes seven parks in western Washington and the northwestern corner of Oregon. They include parks that are coastal, continental, or both. They include four small parks with lesser needs for remote sensing and three larger, mountainous parks. All have terrestrial monitoring questions that might be addressed remotely, including land-use patterns outside of park boundaries, vegetation pattern, and disturbance patterns. Coastal parks are also interested in shoreline position and subtidal changes. Parks with significant aquatic resources are interested in habitat characteristics of streams and rivers including changes in channel morphology, and recruitment and movement of large woody debris. (See Appendix C for a more complete list.)

<u>Ebey's Landing National Historical Reserve</u> (EBLA) is a 7,044 ha reserve established in 1978 to preserve and protect a rural community on Whidbey Island. The historical landscape looks much like it did a century ago – a mosaic of farms, forests and century-old buildings and homes. Outstanding resources include miles of marine shoreline, Penn Cove, three large native prairies, multiple glacial kettles, the island's best farmland, high seaside bluffs, low rolling hills, shallow brackish lakes, and a long, narrow, rugged beach along Admiralty Inlet. This diversity of features provides habitat for a large number and diversity of plants and marine animals. Shoreline movement and land-use patterns are monitoring needs for the park that might be addressed with remote sensing.

<u>Fort Clatsop National Memorial</u> (FOCL) is a 658 ha park at the extreme northwestern corner of Oregon, where the Columbia River meets the Pacific Ocean. It was established in 1958 to commemorate the furthest point of the Lewis and Clark expedition. The park includes estuarine mudflats, tidal marshes, shrub and forested swamps and upland coniferous rainforest. Flora and fauna diversity within the memorial are high, reflecting the park's diversity of habitats, moderate climate, location along the Pacific flyway, and proximity to the Pacific Ocean. Monitoring needs include shoreline movement and land-use patterns.

Fort Vancouver National Historic Site (FOVA) is located along the Columbia River, across from Portland. Its 69 ha were protected in 1948 to preserve the site of the original Hudson's Bay stockade with sufficient surrounding land to preserve the historical features of the area. The natural environment of the site has been heavily impacted over time by the Hudson's Bay Company and by US Army development beginning in 1849. As a result, none of the site's historic natural environment remains. The park's greatest interest in remote sensing relates to handheld instruments used to locate archaeological resources, a topic not covered by this workshop, positions of old flood plains and possible changes in the Columbia River.

San Juan Island National Historic Park (SAJH), established in 1966, covers 709 ha in two pieces on San Juan Island in the Georgia Strait. The two parts protect the sites of American and British military emplacements meant to protect their interests prior to the final settlement in 1871 of the Oregon Territory boundary dispute. Natural habitats include miles of shoreline and intertidal habitat, wetlands, grasslands and some second growth forest. These host a diversity of plant and animal species. The park's interest in remote sensing relates to monitoring shoreline change, and extent of exotic plant species and rabbit warrens.

Mount Rainier National Park (MORA), established in 1899, includes 95,395 ha on the west side of the Cascade Range, surrounding an active volcano and covering a 12,800 ft elevation gradient. Approximately 58 percent of the park is forested, 23 percent is subalpine parkland, and the remainder is alpine, half of which is vegetated and the other half consists of permanent snowfields. The park includes 26 named glaciers in nine major watersheds, 382 lakes plus rivers, streams and wetlands. The park houses four threatened or endangered vertebrate species in its diversity of plant and animal species. Mount Rainier is one of the large mountain parks where remote sensing might prove most helpful for monitoring.

North Cascades National Park Complex (NOCA) consists of North Cascades National Park, Lake Chelan National Recreation Area, and Ross Lake National Recreation Area. The Complex was established in 1968 to preserve the scenery and natural features of the area while allowing for recreational use and for the development and operation of four hydroelectric reservoirs and two run-of-the-river hydroelectric projects, the use of renewable resources, and mineral development. The Complex covers 277,019 ha at the northern end of the Washington Cascade Range, adjacent to the Canadian border. Aquatic resources are the focus of concern at NOCA, but park staff want to address terrestrial issues with remote sensing as well.

Olympic National Park (OLYM) is covers 373,543 ha on the Olympic Peninsula of Washington, and is said to be three parks in one: rugged, glacier capped mountains, over 60 mile of wilderness coastline, and stands of old-growth temperate rain forest. Habitats and communities of the park include intertidal areas, coastal bogs, temperate rainforests, riparian zones, montane and subalpine forests, alpine fellfields, and glaciers. In addition to the biological diversity found in these communities, the park includes all 5 species of Pacific salmon, among other important fish species, 16 endemic plant and animal species. OLYM has issues of difficult-access and similar coastal and terrestrial monitoring questions as both the small, coastal parks and the larger continental ones.

Vegetation Mapping & Remote Sensing in the North Coast & Cascades Network Parks

(presented by Roger Hoffman, GIS Specialist, Olympic National Park)

The Status of Vegetation Mapping at the North Coast & Cascades Network Parks. Accurate vegetation maps with appropriate detail are the foundation of a monitoring program because changes in vegetation indicate changes in environment at a biologically significant scale. The parks in the NCCN vary in the methods and sources used to create vegetation maps (Table 1).

Table 1. Vegetation maps of NCCN parks

Park	**Description of Vegetation Map[1]**
EBLA	True-color digital orthophotography available soon (30 cm)
FOCL	Oregon Department of Forestry Landsat TM-based, 6 landcover classes
FOVA	City of Vancouver map of tree clusters (no attributes)
SAJH	Photointerpretation of true-color digital orthophotography (done by Dave Peterson and Rob Norheim, University of Washington, 1990s)
MORA	1988 Franklin et al. map of plant associations 1996 Pacific Meridian (Landsat TM) map of tree species and size classes Several photo-based projects covering specific areas
NOCA	1990 Aerial photointerpretation of Stehekin 1993 Map of grizzly bear habitat (Landsat TM) 1996 Pacific Meridian (Landsat TM, see above)
OLYM	1981 Cibula (Landsat MSS) 1996 Pacific Meridian (Landsat TM, see above)

[1]See Appendix J for definitions of acronyms

Examples from mapping efforts at OLYM, including models of plant association groups by Henderson and Peter, were shown. Both the parkwide maps and a detailed map of the Heart of the Hills area were displayed and discussed. The imagery-based products (1981 MSS and 1996 TM based maps) have the advantages of using existing conditions (as measured by satellite measured reflectance values) to generate a map of landcover. The modeling approach can be used to create a map of potential vegetation based on slope, aspect, elevation, geographic position, and other environmental variables, but not actual vegetation. Potential vegetation does not take into account stand disturbance history (such as fire) or recruitment constraints (seed sources).

The satellite-based map products also allow for much more detail. Those maps using the more recent satellite technology such as the 1996 TM-based map allow more detail than their predecessors. The user needs to be cautious when using these finely detailed maps and not assume complete accuracy for each pixel.

Landscape Change Analysis in Olympic National Park. As part of the North American Landscape Characterization project, Roger Hoffman examined landscape change at North Cascades, Crater Lake and Olympic National Parks. He used OLYM as an example to describe the methods and results.

The project used repeat Landsat MSS imagery from the 1970's, 1980's and 1990's to analyze landscape level changes in and around the park. For OLYM, the image dates were: 12 September 1974, 1 August 1986 and 16 July 16 1992. The processing steps were:

- Calibrate to at-satellite reflectance
- Equalize images
- Calculate individual image NDVI's (Normalized Difference Vegetation Index)
- Calculate DNDVI for image pairs (Differences in NDVI between images)
- Identify areas of change
- Identify mechanisms of change

The image analysis readily identified areas of change (both increases and decreases in NDVI). In many of these areas, the mechanism of change was easily identified from the imagery and local knowledge of the land ownership and land-use. Aerial photointerpretation was also used to help determine mechanisms of change. The most widespread changes were due to timber harvest (outside of the park), fire, migration of river channels, changes in glacial and snowfield extents, landslides, and avalanches.

There were several complicating factors in determining the mechanisms of change through image processing:

- Annual Variations in Snowfall
- Annual Variations in Phenology
- Sun Angle & Shadows (due to different dates of imagery)
- Different Tide Stages
- Different Lake & River Levels
- Repeat Disturbances (such as avalanche chutes)
- Partial Pixels (change taking place on scales smaller than the resolution of the imagery)

Case Studies of Monitoring using Remote Sensing. One of the areas of change detected by the above analysis was along Willoughby Ridge in Olympic National Park. Looking at the images from that area in more detail it is apparent what caused the change. Sometime between the 1974 and 1986 images, a large clearcut was created along the park boundary. Then, by the 1992 image, there is an area of vegetation loss extending well into the park. The 1991 TM image shows in greater detail the pattern of vegetation loss extending North into the park. The clearcut was along the top of a ridge and the area of vegetation loss was downhill and also down-wind (the prevailing winds and storms are from the Southwest).

Roger Hoffman also looked at the pattern of landcover change in a managed landscape outside of the park on USFS land. The patches of change detected by the image processing match very well with the timber harvest records from the USFS. The loss and subsequent regrowth of vegetation associated with logging was readily identified by the image analysis. However, it was learned that to detect changes (even those as drastic as a clearcut) the time-span between image pairs should not be more than about 10 years (more frequent is better). Recovery of a stand after a disturbance could mask the disturbance because NDVI does not effectively discriminate young stands (regrowth) from old-growth stands.

Introduction to Remote Sensing (presented by Warren Cohen, USDA Forest Service, University of Oregon)

Monitoring requires sampling and integration of information at various scales (i.e., spatial and temporal grains and extents). Sampling tools include field data and remote sensing; integration tools include process models and a conceptual framework. Specifically, remote sensing samples emergent properties (i.e., spectral patterns) of the earth from above, which can be interpreted by models to understand the processes we seek to understand. Unfortunately, remote sensing is not a perfect sampling tool because it operates in a complex sensing environment and is subject to atmospheric effects. It also produces massive amounts of digital data – more than we can process or know how to handle.

<u>Passive Optical Sensors</u> sample the electromagnetic spectrum, of which the visible spectrum (sampled by cameras) is only a small part. Some sensors are multi-spectral, meaning that they sample broad, discontinuous spectral bands chosen to maximize the ability to discriminate vegetation from water from bare ground, etc. Examples include IKONOS, ETM+, MODIS and Landsat TM, of which Landsat is the workhorse for regional analyses. Landsat data are free and readily available. In contrast, hyper-spectral sensors sample the visible and infrared spectra in small, continuous bands, providing a complete spectrum, which can be sub-sampled for different applications. This technology can discriminate spectra at the level of chemical bonds, but it is also very expensive. Passive sensors can be mounted on small airplanes, high-altitude airplanes, or satellites. Trends in improving passive sensor technology are towards increasing spectral, spatial, and temporal resolution to improve the capability of mapping patterns at the local, regional, and global scales.

<u>Active Optical Sensors</u> sample the waveform reflected back from an actively transmitted electromagnetic pulse. The technology is known as lidar (light detection and ranging) and can sample waveforms discretely ("small footprint") or continuously ("waveform"). Lidar is usually collected from lower altitudes and provides a three-dimensional view of a landscape. It provides non-asymptotic predictions of biomass, leaf-area index, etc. and describes canopy volume, canopy organization, and canopy- and ground-surface morphology. Lidar is a powerful tool, but is too expensive to be easily used for large areas.

Extrapolating fine-grained, ground-based measurements over broad spatial or temporal extents (i.e., scaling) is an important challenge for ecology in general, and monitoring in particular. A generalized framework for accomplishing scaling involves extrapolating site measurements to broad spatial scales by applying algorithms relating site characteristics to spectral response to remotely sensed spectral images, resulting in maps maps (e.g., land-cover and time-since-disturbance maps). Ecological process models can link site measurements of ecological processes (e.g., carbon-flux) to site characteristics discerned from analysis of remotely sensed images to produce a time-integrated carbon-flux map. Another example is the CLAMS conceptual framework, which derives net primary production from maps of land-cover, leaf-area index, precipitation, temperature, and solar radiation. This is essentially a biogeochemical model applied cell-by-cell to registered GIS layers, some of which are generated from remotely sensed data.

In summary, remote sensing can enable scaling of field-based data in space and time. Success requires a conceptual framework that includes a sampling strategy, geographic databases (e.g., remote sensing, climate) and spatially and temporally explicit algorithms and process models. When designing ground-based sampling, a sampling scheme that explicitly incorporates remote sensing by distributing sampling according to spectral response categories, may help with meaningful spatial extrapolation. Remote sensing is undergoing rapid advance, hence capability and affordability will improve with time. Especially promising is active optical sensing, which enables direct observation of the three-dimensional properties of vegetation.

USGS-NPS Vegetation Mapping Program (Karl Brown, USGS Center for Biological Informatics, Fort Collins, CO)

Development of vegetation community classification and description, and spatial database development is a high priority for the NPS Inventory and Monitoring Program as a basis for developing Vital Signs and Prototype monitoring programs. The overarching goal is a nationally consistent, hierarchical classification scheme that meets high scientific standards, and has a level of detail that is useful to park management. The requirements for this effort include conforming to the Federal Geographic Data Committee (FGDC) standards for vegetation maps and classification, using uniform classification methods throughout the NPS, meeting National Map Accuracy standards, achieving thematic accuracy of >80% per class with a minimum mapping unit of 0.5 ha. The project will be executed by the USGS Center for Biological Informatics, the NPS Inventory and Monitoring Program, local park personnel in cooperation with mapping organizations, Nature Serve, and State Natural Heritage programs. Eventually, maps will be available for more than 270 park units. To date, protocols and standards have been established and underwent two program reviews in 1998, the prototype parks and 16 other parks are completed, and 66 parks are on-going.

The FGDC standards require that vegetation maps be based on sound science that classifies existing (as opposed to potential) biological associations into ecologically meaningful and hierarchically organized categories that can be mapped from imagery. The methods must be broadly accepted, based on standard field methods and the results must be repeatable. The classification system should be flexible and open-ended, well-documented and should be easily cross-walked with other frequently used vegetation classification systems. The classification system categorizes physiognomy and floristics:

Physiognomy:

- Division – dominant life-form (e.g., Tree Dominant)
- Class – spacing and height of dominant form (e.g., Woodland)
- Subclass – morphological & phenological similarity (Evergreen Woodland)
- Group – climate, latitiude, growth form, leaf form (e.g., Temperate, Evergreen, Needle-leaved)
- Subgroup – natural and semi-natural versus cultivated community
- Formation – mappable unit (e.g., Evergreen Needle-leaved Woodland with Rounded Crowns

Florisitics:

- Alliance (Cover type) – dominant species (Douglas-fir Woodland)
- Association (Community) – sub-dominant or associated species (Douglas-fir/Snowberry Woodland)

The methods for developing vegetation classifications involve reviewing the available data and acquiring new data when necessary. One set of field sampling and photo interpretation-based data are used to develop the classification, and another set is used to validate the results. Once a map is produced, its accuracy is assessed by comparing the results with field data, and the product receives a final review. The final results are posted to the internet and include aerial photography, vegetation information, field data, geospatial vegetation information, and accuracy assessment information. Results can be found at http://biology.usgs.gov/npsveg. These products can be used by Parks for general management, planning, fire management, research applications, habitat modeling, and education/interpretive programs, as well as for a basis for monitoring.

The future for remote sensing technology looks bright. Another satellite system similar to the Global Positioning System (GPS), the Wide Area Augmentation System (WAAS), has been launched. It has 3-5 m real-time accuracy and no additional receiver is needed, but it does not work well under tree canopies and the satellites are positioned only over the equator. Better, smaller, less expensive GPS units are coming. They will be more closely integrated into other electronic equipment (e.g., watches, cell phones, data collection devices). Hand-held mapping systems are also being developed (e.g., ERSI's ArcPAD) that will allow one to nearly take a GIS system to the field.

Using Remote Sensing for NPS "Vital Signs" Monitoring (Mike Story, National Park Service)

As the NPS develops long-term ecological monitoring programs, there is potential for using remote sensing to monitor certain "vital signs". To be effective in using remote sensing it is necessary to learn when and how to approach monitoring from a remote sensing perspective. Remote sensing is "the collection of information about an object without being in physical contact with the object." The approach assumes that features or activities of interest exhibit unique qualities that can be recorded and extracted via remote sensing technologies (e.g., spectral signature). Remote sensing technologies detect reflected and emitted electromagnetic radiation from particular objects. The reflected energy may come from the sun (passive sensors) or from energy transmitted from the sensor (active sensor). Theoretically, each object has a unique signature of reflected and emitted energy that can be located in the remotely sensed image and mapped. Unfortunately, this concept is complicated in the real world because the reflected signal is often modified by the atmosphere, the surficial geometry of the object is not uniform, spectral signals of the same types of objects may vary, and features of interest may be smaller than system resolution (spatially or spectrally). Analyzing of remotely sensed data to obtain a useful product is a complicated procedure of correcting data anomalies (e.g., atmospheric and geometric effects), correlating the data with ground measurements, classifying the data, and validating the results.

Vital Signs monitoring is based on the concept that there are elements of ecosystems that indicate its "health" or status (e.g., keystone species, ecological functions, stressors, early-warning indicators, etc.). It is assumed that these elements can be identified and monitored and that the results are an indication of ecosystem health. Constraints to this approach include the accuracy of the conceptual model, and the ability to identify and monitor them. The analysis of monitoring data include comparing data over time, monitoring for change, interpreting the change and having an impact on management.

Coupling monitoring with remote sensing involves choosing the "right tool" for the job in terms of scale (resolution, footprint), "fingerprint"/signature (spectral resolution), and timing (seasonality, repeatability). In other words, the "Right Tool" is a combination of the "right data" acquired at the "right time", correlated with ground-based data, processes to acquire the desired information and validated for reliability. To choose the "right tool" you must identify the feature of interest, then identify the scale, size and location of the feature, identify the anticipated change, and identify the frequency of monitoring. For NPS monitoring, one must decide whether the vital sign is 1) feature specific (e.g., invasive or endangered species) and whether you need to know presence/absence or health/vigor, or 2) function specific (e.g., primary productivity, photosynthesis), or 3) other (e.g., water quality parameters). The "right data" for the vital sign must be able to detect the element or surrogate and its condition at the appropriate spatial, spectral and temporal scales and be affordable.

Monitoring differs from mapping in several ways. Monitoring has a time component, due to repeated efforts, and implies the need for change detection, and it may not require rectification as mapping does. Remote sensing is not a substitute for ground-based data therefore, sample data are required to "train" and validate the results each time data are collected. Processing remotely sensed data for an inventory that will become monitoring when repeated, requires specific analysis techniques. The data must be normalized or standardized among time periods and then the sensed data must be compared, not the classifications that resulted at each time period.

There are a number of options for acquiring and analyzing remotely sensed data needed for NPS monitoring Table 2).

Table 2. Some data acquisition systems and their costs include (the costs and number of scenes represent an example from Great Smoky Mountains National Park).

Source	Resolution	Scene Size	Cost (based on GRSM)
Landsat 7 (multi-spectral imagery)	30/15 m	185 x 185 km	$425/$600/$900
SPOT (multi-spectral imagery)	20/10 m	60 x 60 km	$6000 (2 scenes)
IKONOS	4/1 m	Sold by area	
OrbView 3	4/1 m	8 x 8 km	$7700/$11000 DOQQS (5m)
DOQQs from USGS			$79,200
Videography	Traditional photography		1:12K CIR photography $113,000
Radar (active system that sees through clouds, dust, etc.)			

Lidar (active system, see below)			
Hyperspectral (see below)			
ADAR			1m/4 band $116K plus mosaicing & georeferencing

There are also a number of analysis systems and software, including ERDAS Imagine, ERMAPPER, PCI, IDL/ENVI, IDRISI, TNT-MIPPS, and ArcView. A recent comparison of these can be found at http://www.geoplace.com/gw/1999/0599srev.asp. It is simply a matter of choosing the one that best meets project needs and the amount of analysis that will be done in-house (i.e., in NPS at the park, network, or regional level). Analysis can also be contracted, arranged through a CESU or other academic institution, or through other state or federal agencies (e.g., USGS, NASA, etc.). To maximize the chance of success with remote sensing, it is necessary to consult qualified experts, use appropriate ancillary data (e.g., DEMs, texture, variance, etc.), closely tie results to ground-based data and validate the results. In summary, if appropriate technologies and analyses are matched with specific vital signs, it is possible to successfully use remote sensing for NPS monitoring.

Examples of Remote Sensing Projects (see http://edc.usgs/earthshots/slow/tableofcontents; Table 3)

Table 3. Examples of remote sensing projects.

Location	Project	Technology	Contact
Hubbard Glacier, SE Alaska	Monitor blockage of Russell Fiord by the glacier terminus	Landsat TM	
Entire USA	GAP and MRLC landcover data; 21 classes for MRLC, FGDC classes for GAP	Aerial photography	http://landcover.usgs.gov/nationallandcover.html http://www.gap.uidaho.edu/
Theodore Roosevelt National Park	Monitor spread of leafy spurge, an exotic plant that forms a dense monoculture	AVIRIS (hyperspectral)	Ralph Root, USGS
Assateague Island National Park	Monitor changes in beach morphology (pattern of accretion and erosion)	Airborne Scanning Altimeter with kinematic GPS	
Global	Monitor changes in gross primary productivity	Landsat TM	

Specialized Remote Sensing Techniques (see Wilkie and Finn 1996 for remote sensing basics)

Hyperspectral Imaging (presented by Marie-Louise Smith, US Forest Service Northeast Research Center and Ralph Root, USGS Rocky Mountain Mapping Center)

Unlike multi-spectral imaging, which samples a few broad, non-contiguous bands of reflected electromagnetic radiation, hyperspectral imaging samples scores to hundreds of narrow, contiguous wavelength bands to give a nearly continuous image of the optical/infrared electromagnetic spectrum. By capturing such fine spectral resolution, hyperspectral imaging is a tool for mapping materials by detecting reflectance characteristics generated by specific chemical bonds. It has been used for mineral mapping, vegetation mapping, environmental assessments, health studies and general land management studies. A number of types of sensors are available with differing costs and resolutions (Table 4).

Hyperspectral data require a significant amount of pre-processing before they can be analyzed. First, they must be calibrated to the radiance present at the time the data were collected. The agency or company providing the images usually handles this. Atmospheric effects must be removed based on data taken during the flight. This is usually done by the end-user using appropriate software (e.g., ACORN, HATCH, MODTRAN-4). Finally, the images must be calibrated to surface reflectance measured on the ground with hand-held sensors, usually accomplished by the end-user. Ground-collected spectra can then be used to identify materials in the image.

Analysis of the images can be done either of two ways. Mapping can be done by matching reference spectra (obtained either from the ground for from the imagery) with imagery spectra (known as "spectrum matching" or "supervised classification"). Alternatively, mapping can be done by a principal components analysis, which identifies "end-member" spectra intrinsic to the image (known as "unsupervised classification"). Non-proprietary software for spectrum matching is available from USGS. It requires a UNIX computer system and is challenging to learn. The best commercial software for spectrum matching is ENVI (Environment for Visualizing Images), but TNT Mips is as good, and ERDAS is improving.

Table 4. Types and characteristics of hyperspectral sensors.

Altitude	**Sensor**	**Resolution**	**Cost**
From Space	Earth Observing -1 Hyperion (EO-1 Hyperion; experimental)	30 m	$1500 per 7.5 x 100 m swath
High Altitude (70K ft.)	Airborne Visible-Infrared Imaging Spectrometer (AVIRIS)	17 m	$68K plus $6K per flight hour
Low Altitude from NASA (6K – 30K ft.)	AVIRIS	4 m	¼ to ½ of high altitude AVIRIS but product is smaller area
Low Altitude from contractor (6K – 30K ft.)	Compact Airborne Spectrographic Imager – 2 (CASI-2) PROBE-1 Hymap Aurora	4 m	$25K-$30K for 10 x 10 km area
Ground level	ASD	< 1 m	???

(handheld-35 lb.)	GER		

One promising use of hyperspectral imagery is to explicitly map patterns of forest processes (e.g., productivity, nitrogen status, soil C to N ratio) across large areas by extrapolating relationships determined in plot-level studies. In the forests of New Hampshire, plot-level studies determined that canopy foliar nitrogen (N) was the strongest predictor of aboveground net primary production and wood production across a range of coniferous, deciduous and mixed forests. Canopy N was also correlated with soil N-mineralization and net nitrification. Using AVIRIS images from space, these processes could be extrapolated across the landscape based on levels of foliar N described in the images. Soil carbon to N ratio could also be extrapolated fairly successfully based on canopy lignin to N ratios determined using imagery. The ability to extrapolate productivity and N status over large areas is important for determining the global carbon budget, monitoring forest health, and understanding soil and drainage water chemistry (Ollinger, et al. in press, Smith et al. 2002).

Hyperspectral imaging has also been used successfully to map the encroachment of leafy spurge into native vegetation in Theodore Roosevelt National Park. The project was successful because leafy spurge has a distinctive spectral signal compared with the grasses it invades. Moreover, it forms solid patches that are often larger than the resolution of the sensor.

Hyperspectral data are extremely powerful for mapping specific environmental elements and processes at the landscape scale, but the technology also has some limitations:

- The technology is very expensive.
- It is not suitable for mapping vegetation because individual plant species or community associations can only be distinguished if they produce distinct spectral signatures, the signature doesn't change during growing season, they have a patchy distribution and the spatial and spectral resolution of the sensor is adequate.
- There are more steps and different algorithms used for analysis than for multi-spectral images.
- Special expertise is required for analysis.
- The data volume is orders of magnitude greater than with multi-spectral images.
- A substantial computational capability is needed.
- It is necessary to collect field spectra for calibration and verification.

<u>Waveform Lidar</u> (presented by Andy Hudak, USFS Rocky Mountain Research Station, and Michael Lefsky, Colorado State University)

Lidar is an active remote sensing technique, analogous to radar. Rather than collecting reflected solar energy as traditional remote sensing instruments do, a lidar instrument emits laser light and measures the time it takes for the light to return. The word "lidar" is derived from "light detection and ranging." The time for light to return is converted to distance, using the speed of light constant. In terrestrial applications, light in the near-infrared (1064 nanometers) is used. At present, lidar instruments are used in aircraft. Precise location information for the aircraft from 3-D GPS equipment allows inference of the position of objects reflecting the laser light.

Two distinct types of lidar instruments are in use for natural resource applications. "Discrete return" (or "small footprint") lidar instruments record one to five returns for each pulse of light emitted. "Waveform-recording" (or "large footprint") lidar instruments continuously record the time and amount of energy returned from each pulse of light. Discrete return lidar is commercially available and is most often used for precise mapping of topography. At present, waveform lidar is a research tool. It obtains a sample of a study area, unlike discrete return lidar which can be used to comprehensively survey an entire area. Waveform lidar tends to have superior vertical resolution, while discrete return lidar excels in horizontal resolution. One particular strength of waveform lidar is the capability to look beneath forest canopies. The continuous record of returned energy can be interpreted to yield canopy height, canopy cover, and the vertical distribution of reflecting surfaces (mostly foliage).

In a research project in Douglas-fir forest in Oregon, waveform lidar successfully measured tree height, forest biomass, and leaf area index. Relationships between ground measurements and lidar-based estimates were nonasymptotic, which is not the case for traditional remote sensing. Waveform lidar can also be used to measure the three-dimensional structure of forests, indicating gaps in both the horizontal and vertical dimensions.

Potential applications of waveform lidar for resource management include timber surveys, fire and fuels management (e.g., ladder fuels), and wildlife habitat monitoring (e.g., mapping old-growth forests). Satellite-borne instruments are planned that may sample forests around the globe. For both aircraft- and satellite-borne instruments, one important technical challenge is how to make inferences from measured swaths tens of meters wide to entire areas of interest.

<u>Small-Footprint Airborne Lidar</u> (presented by Michael Renslow, Spencer B. Gross, Inc.)

Lidar technology has existed for about 30 years, but only recently became cost-effective. The system used by Spencer Gross includes a laser scanner, differential GPS, inertial measurement unit (records tilt and roll of sensor), and a precise clock. The components are controlled with a laptop computer. For each mission, calibration is performed using ground control points to correct for various system biases and timing issues.

The system can be configured in a variety of ways, allowing the possibility to vary the number of returns received per pulse and the spacing of pulses. In addition to deriving the position of each return, intensity can be recorded. This is useful because different types of natural and constructed surfaces vary in reflectivity. Accuracy of point locations is approximately 1 m in the horizontal and 0.3 m in the vertical, with relative accuracies approaching 5 cm.

Components of quality control/quality assurance for data collection include a well-defined flight plan, base station referencing, and performance verification. The flight plan includes flight lines, field of view, scan rate, and the design for post-spacing of points. Base station referencing consists of a GPS check-survey and report. The base station needs to be within 60 km of the project site. System verification includes acquisition of data for control points near the base station, and use of a known target and ground surveys at the project site. Steps in pre-processing of data include differential GPS correction, removal of noise, formatting of multiple-return data sets, verification of coverages, checking of accuracy against known data, archiving to CD-ROM, preparing a "Report of Survey," and visually examining the data in three dimensions.

For many users, the end product is a "bare earth" digital elevation model (DEM). The first data reduction step is automatic removal of returns suspected of representing vegetation. The automatic procedures typically remove about 80% of the returns associated with vegetation but account for only about 20% of the time necessary to generate the bare earth DEM. Manual intervention is required to remove the last 20% of the vegetation returns, and uses up about 80% of the time for this task. This step depends on supporting imagery, and is carried out using custom selection routines in 3D and GIS software. Final quality control on the bare earth DEM is accomplished by comparison to imagery, especially stereo photogrammetry. It is possible to use existing air photos or remote sensing imagery, or to use imagery captured during the lidar flight.

Digital elevation models from lidar are of excellent quality and higher precision compared to existing data (e.g., 10-m DEM from USGS). The DEMs form the basis for comprehensive mapping and classification of stream and road networks, and areas of landslide hazard. The ability to map subtle terrain features (e.g., tire tracks), and hard to survey areas (e.g.,steep slopes, mud flats, intertidal areas) give lidar potential for restoration and other natural resource applications. Since lidar remote sensing exploits emitted rather than reflected light, data can be collected at night if necessary to take advantage of low tides. Another helpful feature is that the data are prepared in a format that is ready to use in GIS.

Small-footprint lidar can also be used to measure vegetation. In the same area studied with waveform lidar, small-footprint lidar was successfully used to measure tree height, tree basal area, and tree bole volume. With multiple returns, a variety of other vegetation parameters can be estimated, including canopy cover, multiple canopy layers, and understory vegetation. With a grid of flight lines "wall to wall coverage" of an area is possible. Allowing time for post-processing, stand characteristics for a 100,000 ha forest can be calculated in a few months. In addition to average values, problem areas with high tree mortality or poor growth can be identified.

Remote Sensing Conducted by Other Agencies

Northwest Forest Plan Integrated Forest Mapping (presented by Melinda Moeur, U.S. Forest Service, Region 6; see Weyermann and Fassnacht 2000)

Federal land management agencies in Oregon, Washington, and northern California are working together, through monitoring, to evaluate the success of the Northwest Forest Plan (NWFP) in achieving objectives on federal lands for conservation, ecological integrity, and economic sustainability. One of the key, general monitoring questions is whether the NWFP is providing for conservation and management of late-successional and old-growth forests as anticipated. More specific questions address status (amount and distribution, structure and composition, patch size, amount of edge), trends (change in amount and distribution, change agents, consistency with NWFP expectations), and estimation error. The Interagency Regional Monitoring Program is addressing these questions using remote sensing and forest inventory data.

The overall objective of the Interagency Vegetation Mapping Project (IVMP) is to produce a consistent and continuous map of forest vegetation for the entire NWFP area. End products are separate maps of total vegetation cover, conifer cover, broadleaf cover, and tree size (quadratic mean diameter). Maps are generated from Landsat 5 Thematic Mapper (TM) imagery. Forest inventory plots (from Forest Inventory and Analysis and Continuous Vegetation Survey programs) and associated air photo interpretation data are used to develop regression models between the mapped variables and transformed TM data. Regression models and vegetation maps are developed separately for the nine physiographic provinces into which the NWFP area is divided.

Accuracy of each map is assessed quantitatively to give users an indication of the quality of each map and its appropriateness for various uses. Some of the plot and air photo data assembled for development of regression models are excluded from regression analysis and saved for accuracy analysis. For each map, overall accuracy (e.g., plots correctly classified divided by total number reserved plots) is reported, along with accuracy for different ranges of values of mapped variables.

In addition to mapping current vegetation, the IVMP is using repeated remote sensing to track disturbance and forest growth and succession. In addition to paired images separated by 5-year intervals, agency activity records, fire reports, aerial insect and disease surveys, and plot data allow identification of a variety of disturbance agents such as harvest and wildfire.

North Coast and Cascades Network parks occupy parts of 5 physiographic provinces in the IVMP (Coast Oregon, Eastern Washington Cascades, Olympic Peninsula, Western Washington Cascades, Western Washington Lowlands). Vegetation maps for all five provinces can be obtained from the IVMP website (www.or.blm.gov/gis/projects/vegetation/ivmp/), along with accuracy assessments and other background information.

Annual Pacific Northwest Aerial Survey (presented by David Bridgwater, U.S. Forest Service, Region 6)

Every year since 1950, USDA Forest Service, Washington Department of Natural Resources, and Oregon Department of Forestry have collaborated on an annual aerial survey of forest damage. Surveys are usually conducted in July, when signs of most disturbance agents are visible from the air. Prior to 2001, the methodology had changed very little. Observers looked out the aircraft window and sketched the location of damage on a paper map at a scale of 1:100,000.   In 2001, a digitally-assisted sketchmapping system was added to the manual sketchmapping. The digital system uses a touch-sensitive computer screen displaying the airplane's current position on user-defined electronic background maps. This system utilizes real-time global positioning and eliminates problems associated with observer disorientation. Although it speeds up data processing, the new system can be challenging when mapping large, landscape-scale events. Planned improvements and increased experience should help compensate for this shortcoming in the future.

During observation, the aircraft is usually 500 to 2000 feet above the terrain. Both grid and contour flight patterns are used. There are two observers looking out opposite sides of the aircraft. Damage is recorded out to two miles on each side. After the flight, paper maps are scanned, and maps from the two observers are combined. Only the current year's damage is recorded. Most recorded agents are insects or diseases, although wind, fire, and bear damage are among the disturbance agents recorded. Quality of the data recorded is influenced by the skill of the observers, atmospheric interference, and timing of flights versus occurrence of the damaging agents.

Each year, data from the aerial survey is summarized in maps and tables. Maps are produced as GIS layers. Affected polygons are identified by the specific damaging agent (e.g., insect species) and the intensity of damage (usually trees per acre, or low/medium/high). Details of mapped information are available on the web (http://www.reo.gov/fid/iddatadictionary.htm). The maps also indicate areas missed by the aerial survey. Tables list area affected and number of trees killed by the various damaging agents, broken down by ownership.

The survey covers a large area relatively quickly, and at a distance, and represents what each observer sees, integrates, and draws on a map as the aircraft travels along. Thus, the accuracy of the cause, size, or intensity of any particular polygon may be limited. Since the aerial survey uses highly skilled observers and consistent methods, the data are best suited to assessment of trends over time, and summarizing the status of relatively large areas.

<u>FIA Photo Interpretation</u> (presented by Dale Weyermann, USDA Forest Service Pacific Northwest Research Station)

The Forest Inventory and Assessment (FIA) program conducts forest monitoring nationwide. The distribution of individual monitoring plots is based on a hexagonal systematic grid. A single hexagon that includes all of the lower 48 states is subdivided into approximately 28,000 Phase III hexagons. Each Phase III hexagon is subdivided into 27 Phase II hexes each about 6000 acres. One-tenth of these Phase II hexes are selected each year for sampling. Exact plot locations within the hexagon are determined using aerial photo interpretation. Sixteen photos are evaluated to choose each plot. However, the FIA is mandated to begin using Landsat TM for this purpose by 2003 or 2004. Even with the Landsat based stratification, though, 2-10% of the points require photointerpretation for final selection.

FIA has used a wide range of aerial photography scales (1:60,000, 1:40,000, 1:31,000, 1:24,000, 1:12,000) and films (true color, color IR, black and white, all in both transparencies and photo-positives). They have archives dating back to the 1960's with some areas represented by several generations of photos.

While they are constantly evaluating new technologies for cost-savings and accuracy improvements, there is a simple elegance to having a medium such as an aerial photo that requires no additional hardware to use and can be taken into the field. They can be annotated, and a pinprick on a photo is permanent documentation of a plot location put in the context of surrounding features.

There are pros and cons of aerial photo interpretation:

Pros:

- Portable – no hardware
- Stereo vision
- Easy to access multi-temporal scenes
- Ability to target special projects
- Many formats, multi spectral
- Useful for prescreening areas you might want to buy imagery for

Cons:

- Photo-interpreters are becoming hard to find
- Cost/Availability may be prohibitive – some sources in Washington include BLM Resource Photos, WA Department of Natural Resources
- They are not orthophotos (although they can be reverse engineered)

<u>Puget Sound Lidar Consortium</u> (presented by Ralph Haugerud, USGS, University of Washington, see www.pugetsoundlidar.org)

The Puget Sound Lidar Consortium (PLSC) is an informal group of local agency staff and Federal research scientists developing public-domain, high-resolution lidar topography and derivative products for the Puget Sound region. Legally, the PSLC is merely a set of inter-agency purchase agreements that allow purchase of lidar surveying via a contract negotiated by Kitsap County. The group coalesced around the issue of earthquake hazards and includes the City of Seattle, the Puget Sound Regional Council, several counties around Puget Sound, NASA, and USGS. Funds have come from NASA, USGS and local funds from the political entities in the consortium.

With adequate funding, lidar can provide large-area, high-resolution surveys. The PSLC is mostly interested in topography, so they use 2 passes of approximately 1 pulse/m2. Of interest to the national parks might be tree canopy and bare-earth topography and canopy void space. This would provide a map base for other inventories and monitoring. In order to undertake change detection, the first survey must be dense (and expensive) but repeat surveys can be less dense and more affordable. In general, lidar will cost $1 per acre, with high relief and bad weather costing more. National Park areas already covered by the PSLC or others include Ebey's Landing, Fort Vancouver, a small area on the north edge of the Olympic Peninsula, 17 mi^2 of Mount Rainier, and San Juan Island should be completed in the next few years. These data are available for evaluating their usefulness to the parks.

The following elements are required to build a new consortium:

- Someone who has experience writing lidar contracts

- A professional surveyor
- A non-federal (agile) contracting agency
- Geologists for quality control
- GIS talent

Recommended Strategy for Monitoring NCCN Parks

After hearing from individual work groups, the final group discussion focused on what a remote sensing monitoring program for National Parks might look like. (See Appendices D-H for work group reports.)

Basic Needs

- Aerial Photography, color, stereoscopic pairs. The experts felt that if you can have only one type of data, it should be aerial photographs. Photos capture changes having small spatial extent (e.g., tree line change), they have high resolution (e.g., for distinguishing tree species) and they are a good resource for validating other forms of remote sensing. Finally, they are important tools for navigation. The frequency of photos should be driven by the monitoring question, but it is more likely to reflect the ability to acquire photos. It might be practical to do a segment of the park every year until the entire park is covered, then repeat the cycle. The parks should find out about the DNR and USFS cycles and partner with them. Administratively there are two ways to extend funds into another fiscal year to "save" adequate funds for regularly delivered products, 1) transfer funds to another federal agency using a "non-severable products" clause in the contract, or 2) tranfer money to GSA's information transfer program that allows extension of year-end funds for a 5-8 year period. GSA charges something like 5% to extend the money. With care given to quality, it is possible to obtain stereophotography that can be used to measure tree heights and bare-earth surface where it is visible (contact Ralph Root for information). Digital ortho-photos can be used as a way to fill-in between the years with aerial photos, but they are disappointing by themselves.
- Vegetation Maps. It is important to have vegetation maps with known accuracy. The parks should evaluate the maps they have by comparing them with IVMP data to see whether they are accurate at the IVMP level. If so, accuracy should then be checked with aerial photos and ground- truth.
- Bare-earth Profiles. Lidar can provide a detailed morphologic map of landscapes that describes the "bare-earth" surface. It is important for understanding, extrapolating and modeling all other aspects of the monitoring program. The cost is prohibitive now, but the group strongly encouraged parks to consider lobbying NPS leaders and Congress, and to persist until they are successful. Emphasizing the success of lidar in identifying geologic hazards might be useful, because anything that might pose a risk to a metropolitan area will provide leverage. It might even be worthwhile to go after some Homeland Security funding. In the meantime, some lidar data are available and worth working with.

Landscape-Scale Issues

- Landsat TM

- IVMP data
- Forest Service Overflights (pest mapping)

These can meet many of the park needs for cover, structure, change metrics and disturbance, and the data are free. These are good basic foundational data that allow uniform coverage across parks and to ask additional questions. More detailed questions will require different types of data, however. The NCCN also has personnel, equipment and software to analyze the images. However, the parks could benefit from more expertise in using these data, especially in the area of deciding which metrics to use.

Standardization among parks in the network and nationally is an important need. The need for vegetation maps derived from remote sensing to be consistent is a requirement of the I&M program. Parks must also agree on a protocol and metrics for deriving information from the sources listed above and on methods for validation.

Special Projects, Finer Scale

- High Resolution Photography. 1:6,000 or 1:10,000 photographs of small areas could be used to look at local issues. They have been used at MORA to look at elk-trailing. They also might be used for monitoring the Elwha and high-elevation recreational impacts.
- Videography can be used to monitor large woody debris in streams and on the coast. BLM has used fixed wing aircraft for beach logs, and helicopters for rivers. A GPS control can be stamped on the images and frames can be frozen for analysis. Thermal features, such as wildlife, can also be detected this way.
- Lidar could be used for geomorphology of the Elwha, special habitat projects, stream channel morphology, etc. Cost is the limiting factor. Collaboration with the Puget Sound Lidar Consortium should be considered.
- Photogrammetry could be used to monitor glacier size.
- FLIR will detect stream temperatures.
- Hyperspectral imaging could be used for ecosystem processes, but it is expensive. MORA has been flown with AVIRIS to look for hydrothermally-altered rock.
- Radar is useful for cloudy areas.
- Classified Government Data. Some high resolution imagery is available from the government to those having a secret level security clearance. Ralph Root, Karl Brown, and Mike Storey have clearances. Clearance can be obtained for $200, a limited background check, a signed disclosure, and a letter of request from a park superintendent. The form is SF-86 and must be renewed every 5 years. Avoid trying to get a renewal when an administration changes because it will take a very long time. This technology would be useful for assessing elk trailing or other fine-resolution changes.

Required Core Capabilities

Change detection is one of the most basic components of any remote sensing program. It might be a cost-effective tool used as a first cut in identifying potential problems in the park. However, “change” is a broad concept, and you must identify “change in what” to determine what technique to use. Doing fundamental change-detection studies should be part of the NPS core-capabilities. This includes being able to bring together different types of data for the synergy that separate data sets cannot achieve. Effective remote sensing throughout the NPS will require capabilities at all levels of management. It is important that the parks invest in the platform and skill-base to support these core-capabilities. The parks should not be dependent on universities or contractors for this.

National (These are the USDA Forest Service capabilities taken from their website as a starting place for the NPS.)

The Remote Sensing Applications Center co-located with the Geospatial Services and Technology Center together provide national assistance to agency field units in applying the most advanced geospatial technology toward improved monitoring and mapping of natural resources. Services include:

- Training
- New Technology Evaluation
- Applications Development
- Technical Support
- Operational Support (for fire-fighting)
- Cooperative Projects
- Federal Programs Liason – NASA, DOI, DOD, NIMA, DOE, FEMA, USGS,BRD,WFRC
- Data Acquisition – acquires all types of data fro field units which results in cost savings through a shared data archive

Regional (taken from Pacific Southwest USDA Forest Service website)

The center undertakes cooperative mapping and resource assessment projects with the California Department of Forestry and Fire Protection. Responsibilities include:

- GIS support to land and resource framework
- Vegetation stand exams with GPS technical support
- GIS and satellite imagery library
- Cooperative work with other regions, state and federal partners

Network

- At least one person with photo-interpretation skills
- Several people with the following skills and background:
    - Academic background in remote sensing including understanding of the capabilities of all forms of remote sensing, analysis capability and knowledge of algorithms, and knowledge of GIS, GPS, spatial statistics and kriging
    - Knowledge of where to find additional resources
    - Good navigational skills (map and compass)
    - Understanding of natural resources and ecological processes
- Equipment -- GIS system

- Software – GIS software (e.g., ARCView) and image analysis software (e.g. ERDAS)

References (cited above and provided at workshop; the list is not at all comprehensive)

Blair, J. B. and M. A. Hofton. 1999. Modeling laser altimeter return waveforms over complex vegetation using high-resolution elevation data. Geophysical Research Letters 26:2509-2512.

Cohen, W., and T. Spies. 1992. Estimating structural attributes of Douglas-fir/western hemlock forest stands from Landsat and SPOT imagery. Remote Sensing of the Environment 41:1-17.

Cohen, W., T. Maiersperger, T. Spies, and D. Oetter. 2001. Modeling forest cover attributes as continuous variables in a regional context with thematic mapper data. Int. Journal Remote Sensing 17: .

Cohen, W., T. Spies, and M. Fiorella. 1995. Estimating the age and structure of forests in a multi-ownership landscape of western Oregon, U.S.A. Int. Journal of Remote Sensing 16:721-746.

Drake, J. B., R. O. Dubayah, et al. 2002. Estimation of tropical forest structural characteristics using large-footprint lidar. Remote Sensing of Environment 81:378-392.

Dubayah, R., J. B. Blair, et al. 1997. The vegetation canopy lidar mission: Land satellite information in the next decade: II. Sources and applications. Washington, DC, ASPRS 100-112.

Evans, D. L., S. D. Roberts, et al. 2001. Detection of regularly spaced targets in small-footprint lidar data: research issues for consideration. PE & RS 67:1133-1136.

Flood, M. 2001. Laser altimetry: from science to commercial lidar mapping. PE & RS 67:1209-1217.

Harding, D. J., M. A. Lefsky, et al. 2001. Laser altimeter canopy height profiles: Methods and validation for closed canopy, broadleaf forests. Remote Sens. Environment 76:283-297.

Hudak, A. T., M. A. Lefsky, et al. 2001. Integration of lidar and Lansat ETM+ data. International Archives of Photogrammetry and Remote Sensing 34:95-103.

Hudak, A. T., M. A. Lefsky, et al. 2002. Integration of lidar and Landsat ETM+ data for estimating and mapping forest canopy height. Remote Sensing of Environment 82:397-416.

Lefsky, M. A., W. B. Cohen, et al. 1999. Lidar remote sensing of the canopy structure and biophysical properties of Douglas-fir western hemlock forests. Remote Sensing of the Environment 70:339-361.

Lefsky, M. A., W. B. Cohen, et al. 1999. Integration of lidar, Landsat ETM+, and forest inventory data for regional forest mapping. International Archives of Photogrammetry and Remote Sensing 32:119-126.

Lefsky, M. A., W. B. Cohen, et al. 2002. Lidar remote sensing for ecosystem studies. BioScience 52:19-30.

Lefsky, M. A., W. B. Cohen, and T. A. Spies. 2001. An evaluation of alternate remote sensing products for forest inventory, monitoring, and mapping of Douglas-fir forests in western Oregon. Canadian Journal of Forest Research 31:78-87.

Lefsky, M. A., D. Harding, et al. 1999. Surface lidar remote sensing of basal area and biomass in deciduous forests of eastern Maryland, USA. Remote Sensing of the Environment 67:83-98.

Lloyd, C. D. and P. M. Atkinson. 2002. Deriving DSMs from lidar data with kriging. Int. J. Remote Sens. 23:2519-2524.

Means, J. E., S. A. Acker, et al. 2000. Predicting forest stand characteristics with airborne scanning lidar. Photogrammetric Engineering and Remote Sensing 66:1367-1371.

Means, J. E., S. A. Acker, t al. 1999. Use of large-footprint scanning airborne lidar to estimate forest stand characteristics in the western Cascades of Oregon. Remote Sensing of Environment 67:298-308.

Nilsson, M. 1996. Estimation of tree heights and stand volume using an airborne lidar system. Remote Sensing of Environment 56:1-7.

Nilsson, M. 1997. Estimation of forest variables using satellite image data and airborne lidar. Umea, Swedish Univeristy of Agricultural Sciences.

Ni-Meister, W., D. L. B. Jupp, et al. 2001. Modeling lidar waveforms in heterogeneous and discrete canopies. IEEE Transactions on Geoscience and Remote Sensing 39:1943-1958.

Ollinger, S. V., M. L. Smith, M. E. Martin, R. A. Hallett, C. L. Goodale, and J. D. Aber. Regional variation in foliar chemistry and soil nitrogen status among forests of diverse history and composition. Ecology, in press.

Plaster, R. L. 2001. Lidar: transitioning technologies from lab to applications around the globe. PE and RS 67:1219-1224.

Smith, M-L., S. V. Ollinger, M. E. Martin, J. D. Aber, R. A. Hallett, C. L. Goodale. 2002. Direct estimation of aboveground forest productivity through hyperspectral remote sensing of canopy nitrogen. Ecological Applications 12:1286-1302.

Wilkie, D. S. and J. T. Finn. 1996. Remote Sensing Imagery for Natural Resources Monitoring: A Guide for the First-time Users. Columbia University Press, New York. 295 pp.

Sun, G. and K. J. Ranson. 2000. Modeling lidar returns from forest canopies. IEEE Transactions on Geoscience and Remote Sensing 38:2617-2626.

Weishampel, J. F., J. B. Blair, et al. 2000. Volumetric lidar return patterns from an old-growth tropical rainforest canopy. International Journal of Remote Sensing 21:409-415.

Weyermann, D. and K. Fassnacht. 2000. The Interagency Vegetation Mapping Project: Estimating certain forest characteristics using Landsat TM data and forest inventory plot data. In: Greer, J. D., ed. Remote sensing and geospatial technologies for the new millennium: Proceedings of the eighth Forest Service Remote Sensing Applications conference [CD-ROM]. Missouri: Mira CD-ROM Publishing.

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Appendix B. Agenda for Remote Sensing Workshop – October 2-4, 2002

Wednesday, October 2

	INTRODUCTION
8:00 – 9:00	Welcome, Introduction to NPS monitoring
9:00 – 12:30	Field Trip to Heart of the Hills and Hurricane Ridge to discuss NCCN natural resources plus goals and constraints for remote sensing – sack lunch
12:30 – 1:00	Break
1:00 – 1:30	Overview of Remote Sensing – Warren Cohen
	REMOTE SENSING TOOLS & USES
1:30 – 2:00	Aerial Photos & Vegetation Mapping – Mike Story
2:00 – 2:30	USGS/NPS Vegetation Mapping Program– Karl Brown
2:30 – 3:00	Waveform LIDAR for Forest Research & Management – Andy Hudak
3:00 – 3:20	Break
3:20 – 4:05	LIDAR/small footprint – Michael Renslow
4:05 – 5:00	Hyperspectral Applications: Leafy Spurge Mapping and Fire Fuels Mapping

Thursday, October 3

8:30 – 9:00	Forest ecosystem processes, canopy chemistry & hyperspectral remote sensing – Marie-Louise Smith
	OTHER PACIFIC NORTHWEST REMOTE SENSING PROGRAMS
9:00 – 9:00	NWFP Integrated Forest Mapping – Melinda Moeur
9:30 – 10:00	USDA Forest Service Overflights – Dave Bridgwater
10:00- 10:30	Break
10:30- 11:00	FIA Photo Interpretation – Dale Weyermann
11:00- 11:30	Puget Sound LIDAR Consortium – Ralph Haugerud
11:30 -12:00	Revisit NCCN goals and constraints, list topics, and form mixed-expertise workgroups
12:00 – 1:00	Lunch

FORMULATING A PLAN

1:00 – 4:00 Address monitoring topics and how we might handle each (includes feasibility, cost, degree of resolution achievable, who else might have useful data, etc.) in workgroups

4:00 – 5:00 Group Reports

Friday, October 4

INTEGRATING THE PLAN

8:30 – 11:30 How can we most efficiently allocate resources to achieve as many of our goals as possible? Hopefully this will be clear after sleeping on the ideas.

Appendix C. NCCN Monitoring Needs That Might be Addressed Using Remote Sensing

The following is a list of potential uses of remote sensing to address monitoring needs in the NCCN parks. Specific questions will be provided to work groups. This list has not been prioritized yet. Two of the factors determining priority will be technical and financial feasibility. At this point we hope to learn how we might (or might not) be able to address this comprehensive list.

- Land use/land cover
- Disturbance
  - Fires
  - Windthrow
  - Avalanches
  - Debris flows/mass wasting
  - Insect and pathogen outbreaks
  - Exotic plants
  - European hares (San Juan Island)
- Vegetation pattern – age, species distribution, physiognomic shifts
- Vegetation chemistry – ecosystem processes
- Coastline movements
- Sub-tidal changes
- Aquatic habitat characteristics
  - Coarse woody debris in streams
  - River channel morphology, position, and consequent vegetation changes
  - Water temperature
  - Timing of glacial flour
- Geologic and topographic changes – specifically Elwha, invnetory at FOVA, but also more generally
- Glaciers/snowpack – amount and phenology
- Cloud cover – as indicator of climate, plant moisture stress

Appendix D. Report from Disturbance Working Group

The disturbance group developed four topics: fluvial processes, fire, human impacts on land cover, and recreational impacts at high elevation. Monitoring fluvial processes would attempt to assess their impacts on infrastructure, biota, and patch dynamics. To detect changes in stream channels, sediment deposits, and riparian vegetation, Landsat data are likely to be too coarse-grained. Lidar is probably the most appropriate technology, though airborne video would be worth considering. Pilot research is needed to determine just how effective lidar would be. In an operational mode, data acquisition will be expensive, so at first the number of watersheds measured would have to be limited. An initial design would be to sample one major watershed in Mt. Rainier, North Cascades, and Olympic National Parks, possibly once every 10 years. It would also be good to be ready to obtain data after particularly eventful storm seasons (e.g., 1996 at Olympic NP). It may be possible to extend coverage to more watersheds if the unit cost decreases over time. Most of the parks in the network can benefit from collaborating with the Puget Sound Lidar Consortium.

Application of remote sensing to fire would involve both retrospective analysis and prospective monitoring. The group recommended analysis of air photos (beginning around the 1940s) and satellite remote sensing data (beginning in the 1970s) to study fire distribution, frequency, and size, and patch dynamics after fire. Landsat data makes possible relatively frequent monitoring at relatively low cost. Monitoring products should be geared to needs of park managers. Attributes to monitor include fuels, urban interface areas, fire spread, and fire severity.

The Interagency Vegetation Mapping Program is in the process of analyzing change over time of land cover. While it would be worthwhile to extend the analysis back in time, it is likely to be difficult due to the large investment that would be necessary to rectify aerial photos, and the spotty coverage of aerial photos in many cases.

Monitoring of recreational impacts at high elevation would focus social trails and trampled areas and how they change over time. The group suggested a combination of high resolution (sub-meter) aerial photos, and on-the-ground mapping with GPS. Monitoring would have to be targeted to specific areas that are suspected of having changing patterns of use.

The group felt their progress was impeded somewhat by confusion over whether to monitor disturbance as a system driver or disturbance as a response. In either case, gathering historic information for “retrospective monitoring” is critical to put contemporary observations into context.

Appendix E. Report from Vegetation Working Group

Vegetation Maps. The vegetation group first discussed the need for accurate vegetation maps at a scale appropriate for project planning. The three larger mountain parks are all working with maps from the same contractor based on remote sensing and ground-truthing. The general sense is that they may not be very accurate and are not good enough for project planning. Potential vegetation maps are also available, based on environmental models, and provide the necessary taxonomic resolution for project planning. However, they are also inaccurate at a small spatial resolution. The group recommended that the current vegetation maps be assessed for accuracy by the parks using ground-based surveys, interpretation of aerial photos and IVMP data. The maps should then be evaluated for the spatial resolution at which they are accurate. Accurate vegetation maps are a necessary starting point for vegetation monitoring. If the parks are not satisfied after the suggested analysis, the national NPS mapping program can help create new maps (and may help with evaluating the current maps).

Vegetation structure can be determined Landsat TM images. A spectral gradient related to structure exists in Landsata data, especially if it is collected during two different seasons. The differing sun angle highlights different structures. For example, patterns of variability in tree size create differences in shadows and sunlit ground that create detectable spectral signatures. The most direct way to detect variability in tree size is related to a third spectral axis (Cohen and Spies 1992, Cohen et al. 1995, 2001). Also, IVMP maps of park vegetation can contribute size information (i.e., overstory quadratic mean diameter) and composition (i.e., conifer versus broadleaf). These maps are currently available and have been assessed for accuracy and can be used to guide NPS end-users in their appropriate use. Finally, special habitats can be targeted with lidar. An example might be marbled-murrelet habitat that is largely defined by structure.

Change Detection. Monitoring vegetation includes detecting change in patterns of structure and composition over time. The group recommended detecting spectral differences between two time periods using Landsat TM images as an effective approach. Images acquired at five-year intervals would be sufficient and basic change detection capabilities (i.e., personnel, software, computer equipment) already exist in the parks. Observed changes can then be investigated in detail using aerial photos and/or visitation. One *ineffective* way to detect change is to compare maps from different time periods, rather than images. The processing used to convert images to maps is not comparable from one time period to another. Some changes will not be visible except at 10-year or greater intervals. The group thought there is validity in knowing what is changing slowly and subtly, even though there might not be utility in tracking slow successional changes over short periods. It might be efficient to focus on vegetation types that are expected to show the most change.

Ecosystem processes can be monitored with hyperspectral images, but the cost is prohibitive. Another approach is to model forest landscapes using Landsat images and existing process models (i.e., Forest-BGC, MODIS). David Turner, Bev Law, Robert Kennedy at OSU, Bob Mckane at EPA, Corvallis and Marie-Louise Smith are potential resources.

Landcover mapping around the parks can also be done using Landsat imagery. New classification categories can be trained to existing park classification (Cohen 2001) and to classifications used by adjacent areas.
Riparian vegetation may not be effectively monitored using satellite imagery. It will be possible to distinguish hardwoods from conifers and large-scale disturbance (e.g., major changes in river course). Riparian vegetation can be better monitored using aerial photos or lidar, although both are more expensive.

The group recommended that remote sensing not be used for monitoring exotic plants, insects and disease, or ozone damage.

Appendix F. Report from Coastal/Intertidal Working Group

Shoreline Changes and Driftwood can be monitored with aerial photography (1:12,000) or videography. Monitoring shoreline changes will be challenging because the depth of the sand will always be changing. Use of lidar would overcome this problem. Oblique land-based photography could also be useful.

Non-native plant species can be monitored with fairly frequent aerial photography. One flight line should be sufficient. Other agencies may already be doing coastal aerial photography so it would be good to investigate that possibility. A pilot study with a hand-held hyperspectral sensor could determine whether exotic species can be distinguished spectrally.

Eelgrass and Kelp have been monitored by the State using CASI.

Off-shore sea surface temperature is being monitored by the Olympic Coast Marine Sanctuary.

The potential for hyperspectral methods to predict DOC, DOM, and turbidity are currently being studied.

Appendix G. Report from Geomorphic/Aquatic Working Group

The geomorphic/aquatic group discussed four issues: coarse woody debris and channel morphology, geologic and topographic changes, stream temperature, and ocean temperature. Aerial photography can be used to describe channel morphology, while videography with integral GPS is the best approach for monitoring wood in channels. Data from these sources can by synthesized using simulation models for wood movement and storage. Gordon Grant of the PNW Research Station in Corvallis has such a model.

The most pressing need for monitoring of topographic changes is associated with the Elwha Restoration Project. The best tools would be lidar and high-resolution aerial photography. Data should be collected before, during, and after dam removal. It should be possible to monitor movement of sediment resulting from removal of the dams.

Stream temperatures, at least for surface waters, can be measured with FLIR (forward-looking infrared imagery). It may also be possible to use FLIR to locate seeps.

No new data collection should be needed for monitoring ocean temperatures. It should be possible to take advantage of data already being collected by NOAA.

Appendix H. Report from Glaciers/Snowpack/Weather Working Group

The workgroup suggested that glacier extent and terminus position might be monitored with photogrammetry, but providing ground markings for photo-registry will be difficult. Ice volume might be monitored with ground-penetrating radar (IFSAR). Lidar could also be used by collecting a baseline at high point density and later doing less intensive measurements. It would be important to do a cost benefit analysis among the three techniques.

Snow volume could be monitored with lidar; snow cover and extent could be monitored with Landsat TM along with modeling based on weather data. Other agencies are also looking at snow, namely NRCS and CREEL (Army).

The group did not see potential for monitoring any aspect of climate with remote sensing, but they did discuss some general issues regarding remote sensing monitoring programs:

- Landsat TM data have multiple applications for NPS monitoring programs. The data are free and readily available from NASA. At the moment, NASA is considering the future of Landsat, including whether it should be privatized. It is important that NPS communicate to NASA and USGS the value of these data for long-term monitoring, including past, present and future data. Nothing from private industry will be as inexpensive as Landsat is currently.

- If it becomes necessary to investigate other types of multi-spectral data, IRS, SPOT and Landsat are all more or less interchangeable. The source of the data isn’t as important for continuity as the type of data.

Appendix I. List of Remote Sensing Websites

Applications
Earthshots http://edcwww.cr.usgs.gov/earthshots/slow/tableofcontents
Landsat 7 http://landsat.gsfc.nasa.gov/images/Landsat_Applications.html
NOAA Coastal Change Analysis Program http://www.csc.noaa.gov/crs/ccap_index.html
SHOALS http://shoals.usace.army.mil/Pages/Welcome_to_shoals.htm
NOAA Topographic Change Mapping http://www.csc.noaa.govcrs/tcm/index.html

Data
http://edc.usgs.gov/programs/NSLRDSA.html
http://see.gsfc.nasa.gov/edu/NPS/
MRLC Data http://edcw2ks15.cr.usgs.gov/lccp/mrlc2k/mrlc2k.asp

Organizations
ASPRS http://www.asprs.org/
Remote Sensing http://www.casi.ca/remote.htm
Open Source http://www.remotesensing.org/

Imaging Systems
AVIRIS http://makalu.jpl.nasa.gov/aviris.html
ASTER http://asterweb.jpl.nasa.gov/
TERRA http://terra.nasa.gov/
Landsat http://geo.arc.nasa.gov/sge/landsat/landsat.html
SPOT Image http:// www.spotimpage.fr/spot-us.htm
Orbimage http://www.orbimage.com/
Space Imaging http://www.spaceimaging.com/
Positive Systems http://www.possys.com/
Spectometer list http://www.geo.unizh.ch/~schaep/research/apex/is_list.html
Digital Globe http://www.digitalglobe.com/
Satellite list http://www.itc.nl/~bakker/launch-table.html

Tutorials
ASPRS Core Curriculum http://www.research.umbc.edu/~tbenja1/index.html
NASA Remote Sensing Tutorial http://rst.gsfc.nasa.gov/
CCRS Learning Resources http://www.ccrs.nrcan.gc.ca/ccrs/learn/learn_e.html
Remote Sensing from Michigan Tech http://www.geo.mtu.edu/rs/
University of Colorado Site
http://www.colorado.Edu/geography/gcraft/notes/remote/remote_f.html
Utah State Site http:// www.nr.usu.edu/Geography-Department/rgis/Remsen1/rslec.html
NASA LIDAR Tutorial http://aesd.larc.nasa.gov/GL/tutorial/lidar/lidar_mn.htm
NASA Echo the Bat http://images.gsfc.nasa.gov/

Software
ERDAS Imagine http://www.erdas.com/
ER Mapper http://www.ermapper.com/

ENVI http://www.envi-sw.com/
PCI http://www.pci-pacific.com/
MicroImage http://www.microimaes.com/
ESRI Image analyst http://www.esri.com/
IDRISI http://www.clarklabs.org/
ArcView LIDAR Extension http://www.csc.noaa.gov/crs/tcm/lidar_handler.html
Review of software http://www.geoplace.com/gw/1999/0599/599srev.asp

Other Links etc.
Links http://southport.jpl.nasa.gov/links/links.html
More links http://sedac.ciesin.columbia.edu/remote/index.html
http://sedac.ciesin.columbia.edu/sites.html
http://www.gislinx.com/
http://www.geoinfosystems.com/resource.htm
http://www.forestry.umt.edu/ntsg/
http://wildfire.geog.csulb.edu/resac/main/welcome/resacs/resacs.htm

Appendix J. Definitions of Abbreviations

ADAR – Airborne Data Acquisition and Registration, digital aerial photography
ARCPad – mapping and GIS software for field-use by ESRi
ASD – Analytical Spectral Devices, Inc., land-based spectrometers
AVIRIS – Airborne Visible-Infrared Imaging Spectrometer (NASA)
CASI-2 – Compact Airborne Spectrographic Imager, visible and near infrared hyperspectral imaging
CLAMS –
DEM – Digital Elevation Model, topography
DNDVI – Differences in NDVI between images
DOQQ – digital orthophoto (with displacements caused by camera orientation and terrain removed)
EO-1 – Earth Observing satellite, platform for remote scanners
ERDAS – Earth Resources Data Analysis System, image analysis software
EROS – Earth Resources Observation System
ESRi – Earth Resource Surveys, Inc., source for images, mapping, orthorectification, etc.
ETM+ -- updated thematic mapper used on Landsat 7
ENVI – Environment for Visualizing Images, software
FGDC – Federal Geographic Data Committee, sets standards for vegetation maps & other data
FIA – Forest Inventory and Assessment, USDA Forest Service national program
GER – airborne and ground-based spectroradiometers (GER is company name)
GIS – Geographic information system
GPS – Global Positioning System, satellite system producing location information
HyMap – Hyperspectral, Mapping, airborne hyperspectral scanner
IFSAR – ground-penetrating radar
IKONOS – multi-spectral and visible scanner made by Space Imaging
IRS – multi-spectral scanner
IVMP – Interagency Vegetation Mapping Project, USDA Forest Service
Lidar – Light detection and ranging
MODIS – Moderate Resolution Imaging Spectroradiometer, 36 bands of wavelengths
MSS – Multi-Spectral Scanner, used on Landsat 1-5
NASA – National Aeronautics and Space Administration
NDVI – Normalized Difference Vegetation Index
NWFP – Northwest Forest Plan
Probe-1 – airborne hyperspectral imager
Radar – Radio detection and ranging
SPOT – Satellite Pour l'Observation de la Terre, multi-spectral and visible imager
TM – Thematic Mapper, multi-spectral imager used on Landsat 4-5
TNT Mips – software for image analysis
WAAS – Wide Area Augmentation System